

# Quantitative analysis of aerosol effects on cloud radiative properties in urban polluted cities

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**Abstract.** Accurate knowledge of radiative effects of aerosols is important for understanding climate change. Aerosols influence the Earth's radiative balance directly by scattering incoming shortwave radiation back to space, or indirectly through their influence on cloud properties. The indirect effect is considered to be one of the largest uncertainties in current global climate models (GCMs). In the present work, the regional influence on the impact of aerosols on cloud radiative properties is studied by analyzing data from MODIS (Moderate Resolution Imaging Spectroradiometer). The MODIS instrument is operating on both the Terra and Aqua spacecraft. It has a viewing swath width of 2,330 km and views the entire surface of the Earth every one to two days. Its detectors measure 36 spectral bands between 0.405 and 14.385  $\mu\text{m}$ , and it acquires data at three spatial resolutions -- 250m, 500m, and 1,000m. We present a case study over Linfen, China, that has ranked consistently as one of the most polluted cities globally. Seasonal variation of aerosol mass concentration and its effect on cloud radiative properties are discussed. The results are compared with four other polluted cities of the world, Los Angeles, USA; New Delhi, India; Mexico City, Mexico; and São Paulo, Brazil. The differences in the results indicate considerable regional influence on aerosol effects.

**Keywords:** Aerosol, cloud radiative properties, urban cities, MODIS instrument

**PACS:** 91.40.Dr

## INTRODUCTION

There has been mounting evidence of the importance of atmospheric aerosols in the context of both climate change and human health effects. Aerosols influence the radiative budget of the earth-atmosphere system in two different ways. The first is the direct effect by the absorption and scattering of solar radiation. The second is the indirect effect, whereby aerosols affect the radiation balance through their effect on cloud microphysical and hence radiative properties.

The aerosol indirect effect (AIE) is usually split into two effects: the first indirect effect is called "cloud albedo" effect, whereby an increase in aerosols causes the increase in cloud droplet concentration and a decrease in droplet size for fixed liquid water content [1] and the second indirect effect, is called "cloud lifetime effect" whereby the reduction in cloud droplet size affects the precipitation efficiency and thus increases the liquid water content, the cloud lifetime and the cloud thickness.

Several observational and model studies are made to evaluate the indirect effect of aerosols. Investigations by Brenguier et al. [2] over the Atlantic Ocean showed that the cloud droplets were smaller in the polluted clouds than in the clean clouds. This contrast between polluted and clean clouds is partially offset because they found that the polluted clouds were thinner and drier.

Satellite data have been proved to impart information about aerosol effects on air quality. Moderate Resolution Imaging Spectroradiometer (MODIS) derived aerosol and cloud data are well suited to analyze aerosol effects on cloud radiative properties. MODIS is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Many data products derived from MODIS observations are studied to understand land, ocean and atmospheric processes and trends on local to global scales. Recently Yuan et al. [3] have studied and discussed the uncertainty of AIE by comparing MODIS data with model studies. The goal of this study is to understand and quantify aerosol indirect effect in local scale.

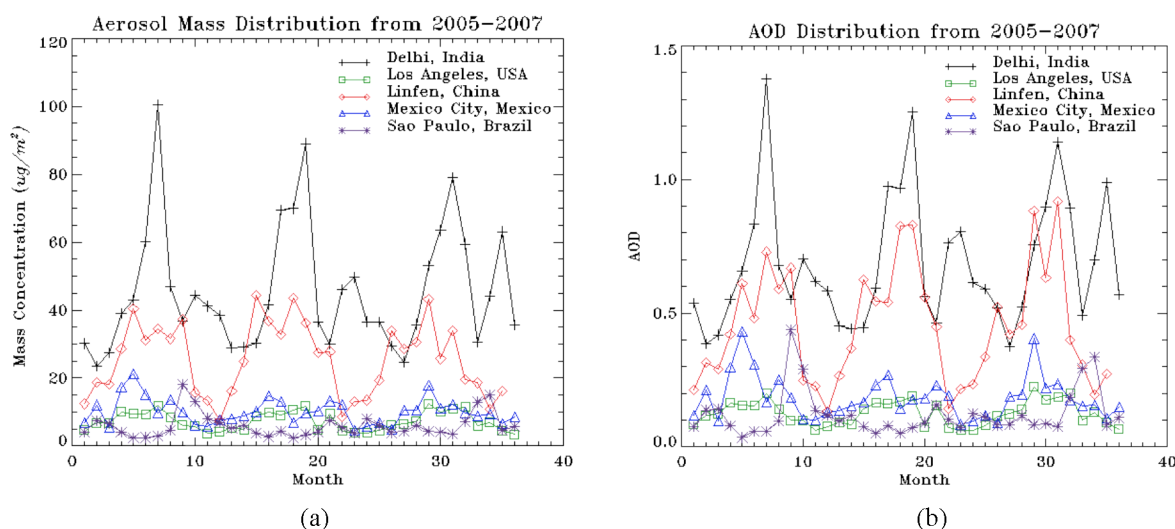
## DATA AND METHODOLOGY

Aerosol optical depth and cloud parameters have been obtained using MODIS collection 5 Level-3 gridded atmospheric data from Terra satellite. Daily and monthly average MODIS [4] product files are available in Hierarchical Data Format (HDF-EOS) at spatial resolution of 1 degree by 1 degree. The present study is based on 36 months of data from MODIS from January 2005 to December 2007.

We analyze MODIS data in 5 polluted cities of the world, Linfen, China (Lat: 36.09 N, Lon: 111.52 E); Los Angeles, USA (Lat: 34.0 N, Lon: 118.2 W); Delhi, India (lat: 28.6 N, Lon: 77.1 E); Mexico City, Mexico (Lat: 19.4 N, Lon: 99.1 W); and Sao Paulo, Brazil (Lat: 23.6 S, Lon: 46.7 W) and quantify aerosol indirect effects. In this work we have used aerosol mass concentration and aerosol optical depth from aerosol product (MOD04) at 550 nm, and cloud products (MOD06) that include cloud optical depth (COD), droplet effective radius (DER), liquid water content (LWP), and cloud fraction (CF).

## RESULTS AND DISCUSSION

Figure 1 shows the variation of aerosol mass and AOD over the 5 cities for 3 years from 2005 to 2007. During the summer months from June to August, both aerosol mass and AOD are found to be significant in Delhi which is attributed to the observed dust events in the northern part of India from the Saharan desert and from the north western dust bowls in Pakistan. From the plots we can see that AOD and aerosol mass are strongly correlated. We find that Delhi has highest AOD values and São Paulo has lowest AOD values. Second highest values of AOD are observed for Linfen.



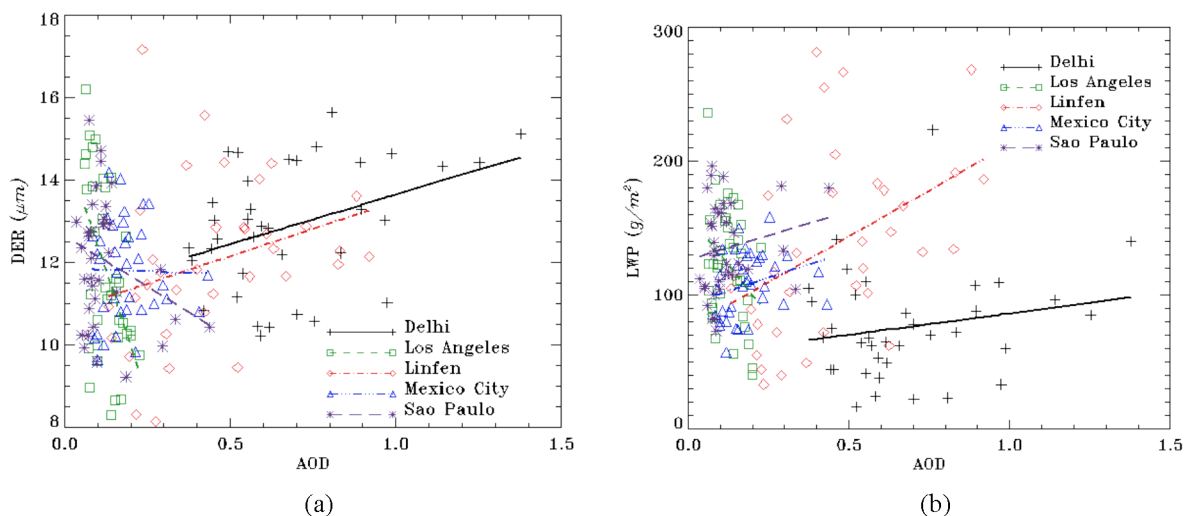
**FIGURE 1.** (a) Aerosol Mass Concentration and (b) Optical Depth Distribution in 5 Urban Cities from 2005-2007

AOD is correlated to the cloud parameters DER, LWP, COD and CF. The correlation data is shown in Table 1. Regional differences are observed in this correlation as both positive and negative correlations of cloud parameters exist at different locations.

**TABLE 1. Correlation of AOD with Cloud Parameters**

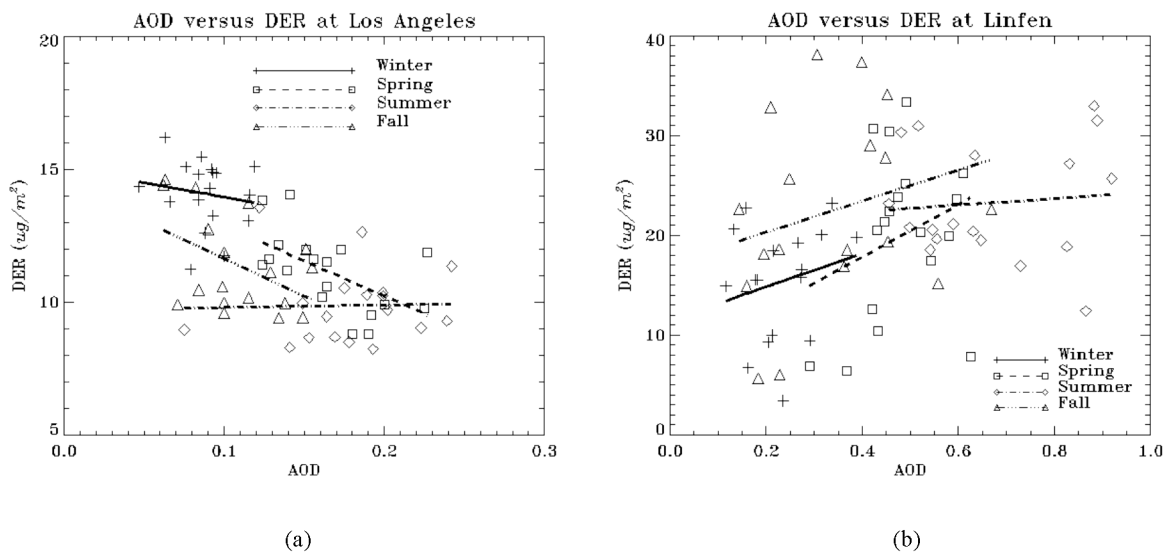
City	Linfen	Los Angeles	Delhi	Mexico City	São Paulo
AOD vs. DER	0.3	-0.522	0.382	-0.018	-0.279
AOD vs. LWP	0.43	-0.319	0.191	0.27	0.185
AOD vs. COD	0.423	-0.176	0.269	0.530	0.239
AOD vs. CF	-0.068	-0.386	0.564	0.209	0.226

To account for the aerosol indirect effect, we have studied the inter-relationship between AOD and DER. We found that for Delhi and Linfen, DER increases with AOD whereas for other three cities, the usual negative correlation exists. Yuan et al. (2008) has recently studied this behaviour of indirect aerosol effect and have identified several explanations such as aerosol swelling, partially cloudy, atmospheric dynamics and surface influence for this effect.



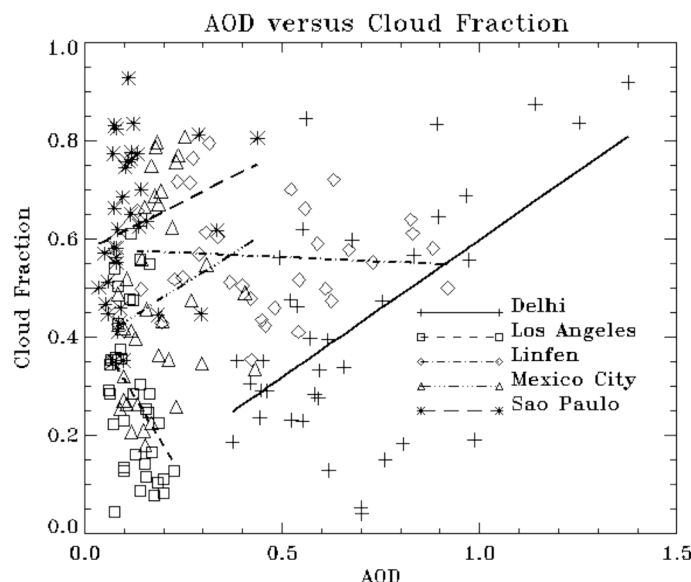
**FIGURE 2.** AOD versus Cloud Droplet Effective Radius

We have studied seasonal effects on this relationship in two cities, Linfen and Los Angeles by using 6 years of data from 2002-2007. The results are shown in Fig. 3. We found that whereas for Linfen DER is positively correlated with AOD for all seasons, for Los Angeles, DER is negatively correlated with AOD in all seasons except summer.



**FIGURE 3.** Seasonal effects on AOD and DER relationship

We have examined the second indirect aerosol effect by evaluating the variation of cloud fraction as function of AOD. This is shown in Fig. 4. We find that for Delhi, Mexico City and São Paulo, positive correlation exists between AOD and Cloud Fraction, whereas for Linfen and Los Angeles, negative correlation exists.



**FIGURE 4.** AOD versus Cloud Fraction

Aerosol indirect effect is the most uncertain among all the mechanisms in the climate system. Our results indicate strong influence of local environment on this effect. However, the limitations of this analysis prevent us from reaching a definite conclusion about the exact regional and local influence on aerosol effects. Further studies are needed to explore this important phenomenon.

## ACKNOWLEDGMENTS

The MODIS data used in this study were obtained from Goddard Earth Sciences (GES) Data and Information Services Center (DISC) Distributed Active Archive Center (DAAC).

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